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METHODS OF DETERMINATION OF EFFICIENCY OF ROTATING ELECTRICAL MACHINES

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BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

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Indian Standard

METHODS OF DETERMINATION OF EFFICIENCY OF ROTATING ELECTRICAL MACHINES

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AMENDMENT NO. 3 NOVEMBER 2011
TO
IS 4889 : 1968 METHODS OF DETERMINATION OF EFFICIENCY OF ROTATING ELECTRICAL MACHINES

(*Page* 5, *clause* **3.1**) — Substitute the following for the existing:

'**3.1 Reference Temperature** — Unless otherwise specified all I^2R losses shall be corrected to one of the temperatures given below:

Class B 95ºC
Class F 115ºC
Class H 135ºC

NOTE — The actual class of insulation used for the particular part of the machine need not necessarily correspond with the selected limits of temperature-rise.'

(ET 15)

Reprography Unit, BIS, New Delhi, India

Indian Standard

METHODS OF DETERMINATION OF EFFICIENCY OF ROTATING ELECTRICAL MACHINES

0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 4 November 1968, after the draft finalized by the Rotating Machinery Sectional Committee had been approved by the Electrotechnical Division Council.

0.2 This standard has been prepared to establish methods of determining efficiencies of machines covered by IS : 4722-1968* from tests, and also methods of obtaining particular losses when these are required for other purposes.

0.3 The choice of tests to be made on a particular machine depends on the information and accuracy requirements, and the type and size of the machine involved. Where alternative methods of testing are available the preferred methods have been indicated (*see* **8**).

0.4 While preparing this standard assistance has been derived from the following documents:

IEC document 2D (United Kingdom) 5 Comments from the British Committee on Document 2D (Secretariat) 7: Draft revision of Publication 34-2.

IEC document 2D (Secretariat) 7 Draft revision of Publication 34-2 Recommendations on methods for determining losses and efficiency of rotating electrical machinery from tests (excluding machines for traction vehicles). International Electrotechnical Commission.

0.5 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test, shall be rounded off in accordance with IS : 2-1960†. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

*Specification for rotating electrical machines.

†Rules for rounding off numerical values (*revised*)

1. SCOPE

1.1 This standard covers methods of determining efficiencies of dc. ac synchronous and induction machines from tests, and methods of obtaining particular losses when these are required for other purposes.

NOTE — The principles can, however, be applied to other types of machines, such as rotary convertors, ac commutator motors and single-phase induction motors for which other methods of determining losses are generally applied.

2. TERMINOLOGY

2.0 For the purpose of this standard, the definitions given in IS : 4722-1968* and IS : 1885 (Part XXXV)-1973†, besides the following, shall apply.

2.1 Efficiency — The ratio of output to input expressed in the same units. It is usually expressed as a percentage.

2.2 Total Loss — The difference between the input and the output.

2.3 Braking Test — A test in which the mechanical power output of a machine acting as a motor is determined by the measurement of the shaft torque, by means of a brake, dynamometer or balance generator, together with the rotational speed. Alternatively, a test performed on a machine acting as a generator, by means of a dynamometer or balance generator, to determine the mechanical power input.

2.4 Calibrated Machine Test — A test in which the mechanical input or output of an electrical machine is calculated from the electrical input or output of a calibrated machine mechanically coupled to the machine on test.

2.5 Mechanical Back-to-Back Test — A test in which two identical machines are mechanically coupled together, and the total losses of both machines are calculated from the electrical input and output of the two machines.

2.6 Electrical Back-to-Back Test — A test in which two identical machines are mechanically coupled together, and they are both connected electrically to a power system. The total losses of both machines are taken as the power input drawn from the system.

2.7 Retardation Test — A test in which the losses in a machine are deduced from the rate of deceleration of the machine when only these losses are present.

2.8 Calorimetric Test — A test in which the losses in a machine are deduced from the heat produced by them. The losses are calculated from the temperature-rises produced by this heat in the coolant or in the surrounding media.

*Specification for rotating electrical machines.
†Electrotechnical vocabulary: Part XXXV Rotating machinery.

2.9 Open-Circuit Test — A test in which a machine is run as a generator with its terminals open-circuited.

2.10 Short-Circuit Test — A test in which a machine is run as a generator with its terminals short-circuited.

2.11 No-Load Test — A test in which the machine is run as a motor providing no useful mechanical output from the shaft.

2.12 Zero Power-Factor Test — A no-load test on a synchronous machine which is over-excited and operates at a power factor very close to zero.

3. GENERAL

3.1 Reference Temperature — Unless otherwise specified all I^2R losses shall be corrected to one of the temperatures given below :

Classes A, E and B	75°C
Classes F and H	115 C

NOTE — The actual class of insulation used for the particular part of the machine need not necessarily correspond with the selected limits of temperature-rise.

3.2 Tests shall be conducted on a completely assembled and sound machine, all devices for automatic regulation not a composite part of the machine itself being made inoperative.

Unless otherwise stated, the tests are taken at rated speed and with all covers fitted as required for normal operation.

3.3 Measuring instruments (*see* IS : 1248-1968*) and their accessories, such as measuring transformers [*see* IS : 2705 (Part II) - 1964†], shunts and bridges used during the tests, unless otherwise stated, shall be of an accuracy class equal to at least 1·0. Instruments used for determining dc resistances shall be of an accuracy class equal to at least 0·5.

3.4 On machines with adjustable brushes, the brushes shall be placed in the position corresponding to the specified rating. For measurement on no-load, the brushes may be placed on the neutral axis.

3.5 Speed of rotation may be measured by a stroboscopic method, a digital counter or a tachometer. It is permissible to deduce speed of a synchronous machine by measuring its frequency.

3.6 A distinction is made between direct and indirect measurement of efficiency.

*Specification for direct acting electrical indicating instruments (*first revision*).

†Specification for current transformers: Part II Measuring current transformers.

The direct measurement of efficiency is made by measuring directly the power supplied by the machine and the power absorbed by it.

The indirect measured efficiency is determined by measuring the losses of the machine. These losses are added to the power supplied by the machine, thus giving the absorbed power.

The indirect measurement may be carried out by the following methods:

a) Determination of separate losses for summation.

b) Determination of total losses.

3.7 When the overall efficiency of the absorbed power is measured for a group of machines comprising two electrical machines, or a machine and a transformer, or a generator and its driving machine or a motor and its driven machine, there is no need to indicate the individual efficiencies. If, however, these are given separately, they should be regarded as approximate.

4. DETERMINATION OF QUANTITIES FOR dc MACHINES

4.1 Losses — The total losses in a dc machine consist of the following.

4.1.1 *Exciting-Circuit Losses*

a) *Field I^2R loss* — The I^2R loss in the shunt or separately excited windings.

b) *Main rheostat loss* — The loss in the rheostat in the main exciter circuit.

c) *Exciter loss* — All the losses in an exciter mechanically driven from the main shaft which forms part of the complete unit, and is used solely for exciting the machine, together with losses in the rheostat in the field circuit of such an exciter, with the exception of bearing loss which is included in **4.1.2** (b), windage loss which is included in **4.1.2** (c), and brush friction which is included in **4.1.2** (d). In case of separate excitation by other means, such as a battery, rectifier or motor-generator set, no allowance for losses of the excitation source shall be made.

4.1.2 *Losses Independent of Current*

a) *Core loss* — Core loss at no-load and rated speed and rated terminal voltage.

b) *Bearing friction loss* — Only losses in bearings supplied with the machine shall be included. Losses in common bearings shall be stated separately whether or not they are supplied with the machine.

c) *Total windage loss* — The total windage loss in the machine and exciter, if any, including the power absorbed in fans forming an integral part of the machine. The losses in external fans provided exclusively for the machine in question shall be included only by agreement. When the machine is ventilated from a common independent air supply, the windage losses in ventilating ducts external to the machine housing, and those of the external fans supplying air through such external ducts, shall not be included.

d) *Brush friction loss* — The brush friction, including that of the exciter if mechanically driven by the machine itself.

4.1.3 *Direct-Load Losses*

a) *Change in core loss due to load* — Change in core loss due to load is difference between the core loss on load and the core loss on no-load [**4.1.2** (a)].

b) I^2R loss in the armature winding.

c) I^2R loss in windings in series with the armature.

d) The summation for the entire machine of the I^2R loss in brushes and connectors and brush contact loss.

4.1.4 *Stray-Load Losses*

a) The stray-load loss in the magnetic circuit and any other metal parts other than the conductors.

b) The stray-load loss in conductors.

c) The additional brush losses due to commutation.

4.2 Determination of Efficiency — The efficiency of a dc machine may be determined by anyone of the following methods.

4.2.1 *Summation of Losses* — The efficiency can be calculated from the total losses which are assumed to be the summation of the losses obtained in the following manner.

4.2.1.1 *Exciting-circuit losses* (*see* **4.1.1**) — These are determined as follows:

a) *Shunt field I^2R losses* — These losses are calculated from the formula I^2R, where R is the resistance of the shunt field winding (or separately excited winding), corrected to the reference temperature

and I is the on-load excitation current. Except for case (3) below, the excitation shall be that corresponding to rated speed at full load. For case (3) below, it shall be that corresponding to rated speed at no-load

If the current cannot be measured during a test on-load, it shall be taken as:

1) For shunt-connected or separately excited generators with or without commutation poles: 110 percent of the excitation current corresponding to no-load at a voltage equal to the rated voltage plus the ohmic drop in the armature circuit (armature, brushes, interpole and compensating windings, if any).

2) For compensated shunt or separately excited generators, the excitation current corresponding to no-load at a voltage equal to the rated voltage plus the ohmic drop in the armature circuit (armature, brushes, interpole and compensating windings, if any).

3) For level-compounded generators: the excitation current for the rated no-load voltage.

4) For over-compounded and under-compounded generators, and special types of generators not covered by items (1) to (3): as agreed between manufacturer and purchaser.

5) For shunt motors: equal to no-load excitation current corresponding to the rated voltage.

b) *Main rheostat losses* — These losses are calculated from the formula I^2R, where R is the resistance of the part of the rheostat in circuit for the rating considered, and I is the value of the on-load exciting current defined as in **4.2.1.1** (a) above. They are also equal to the product IU, of the on-load excitation current multiplied by U, the excitation voltage which shall be absorbed in the rheostat.

The sum of losses **4.2.1.1** (a) and **4.2.1.1** (b) is also equal to the product IU_e of the on-load excitation current I and the total excitation voltage U_e.

c) *Exciter losses* — These losses include the difference between the power absorbed at the shaft by the exciter and the useful power at its terminals*. as well as the excitation losses in the exciter if this is excited from a separate source.

*The useful power at the terminals of the exciter is equal to the sum of the losses **4.2.1.1** (a) and **4.2.1.1** (b) of the main machine.

If the exciter can be uncoupled from the main machine and tested separately, the power which it absorbs may be measured by using the calibrated machine method (**4.2.3**).

If it cannot be uncoupled from the main machine, the power which it absorbs may be measured either by the method of working as a motor on no-load, or by the calibrated machine method (**4.2.3**), or by the retardation method (**7.4**), applied to the whole unit. In these three methods, the power absorbed by the exciter is obtained as the difference between the total losses of the unit measured under identical conditions, with the exciter on-load and with the exciter unexcited, the excitation of the exciter being supplied by an independent source.

If none of these methods is applicable, the power absorbed by the exciter is obtained by adding to the power, measured at its terminals, the different separate losses determined as under **4.1**. However, mechanical friction and windage losses which are measured at the same time as those of the main machine are not taken into account.

NOTE — This applies only to the case where the exciter is mechanically driven from the main shaft and is used solely for exciting the main machine.

4.2.1.2 *Losses independent of current* — The sum of these losses shall be determined by running the machine under no-load conditions as a motor with rated voltage applied and with rated speed achieved by adjustment of the excitation, which shall preferably be derived from a separate source.

The total electric power absorbed, less the I^2R losses in the armature and in the excitation winding or, if necessary, less the power absorbed by the exciter, gives the sum of the losses independent of current.

The losses **4.1.2** (a), **4.1.2** (b), **4.1.2** (c), and **4.1.2** (d) can be determined separately by driving the machine at its rated speed by means of a calibrated motor (*see* **4.2.3**). The machine is excited (preferably from an independent source), so as to work as a generator under no-load at a voltage equal to its rated voltage, the power which it absorbs at its shaft and which can be obtained from the electric power absorbed by the calibrated motor giving the sum of the above losses. By eliminating the excitation, the sum of the losses **4.1.2** (b), **4.1.2** (c) and **4.1.2** (d) is obtained in the same fashion. The losses in **4.1.2** (a) are obtained by subtraction. Finally, by lifting the brushes, the sum of losses in **4.1.2** (b) and **4.1.2** (c) is obtained. The losses in **4.1.2** (d) are obtained by subtraction.

In machines with large inertia, the total losses **4.1.2** (a) + **4.1.2** (b) + **4.1.2** (c) + **4.1.2** (d), as well as the losses **4.1.2** (a) + **4.1.2** (b) + **4.1.2** (c) and **4.1.2** (d), can also be determined separately by using the retardation method (*see* **7.4**).

4.2.1.3 *Direct-load losses* — These are determined as follows:

a) *Change in core loss due to load* — In general, this variation is considered as being negligible. By special agreement for very low-voltage machine, the sum **4.1.2** (a) + **4.1.3** (a) may be measured as described above for the core losses **4.1.2** (a) by one or other of the two methods, by operating as a motor on no-load or as a generator on no-load, but instead of making the test at the rated voltage, the test is made at this rated voltage increased or decreased by the voltage drop in the armature circuit for the current considered, accordingly as it is a generator or a motor.

   For the determination of the change in core losses in machines with a non-uniform air gap, special agreement between purchaser and manufacturer is necessary.

b) *I^2R losses in armature windings*

c) *I^2R losses in windings in series with the armature* — These losses are calculated from the current and the measured resistance, corrected to the reference temperature, except that where resistance measurement is impracticable due to very low resistances, calculation is permissible.

NOTE — Under this heading are included compensating windings, commutating pole windings and diverters In the case of diverters in parallel with a series winding the I^2R losses should be determined using the total current and the resulting resistance.

d) *Electrical losses in brushes* — The sum of these losses shall be taken as the product of the main current and a fixed voltage drop.

   The voltage drop allowed for all brushes of each polarity shall be 1·0 volt for carbon or graphite brushes and 0·3 volt for metal-carbon brushes, that is, a total drop of 2·0 volts for carbon or graphite brushes, and 0·6 volt for metal-carbon brushes.

4.2.1.4 *Stray-load losses* — Unless otherwise specified, it is assumed that these losses vary as the square of the current, and that their total value at maximum rated current is equal to:

1 percent of the basic output for uncompensated machines, and
0·5 percent of the basic output for compensated machines.

For constant-speed machines, the basic output is taken as the output obtained at maximum rated current and maximum rated voltage.

For variable-speed motors where the change in speed is obtained by applied voltage, the basic output is defined at each speed as the output at the shaft, when the maximum rated current at any speed is associated with the applied voltage of the particular speed considered.

For variable-speed motors, whether compensated or uncompensated, where the increase in speed is obtained by weakening the field, the basic output is defined as the output at the shaft when the rated voltage is associated with the maximum rated current, and the allowances for stray-load loss at minimum speed shall be as specified above. The allowances at other speeds shall be obtained by multiplying the figures specified above by the multiplying factor given in Table 1 corresponding to the speed under consideration.

NOTE — The stray-load loss may be obtained from an input-output test or from a pump-back test by subtracting from the total measured losses all other known losses.

TABLE 1 MULTIPLYING FACTORS FOR DIFFERENT SPEED RATIOS

SPEED RATIO	MULTIPLYING FACTOR
(1)	(2)
1·5 : 1	1·4
2 : 1	1·7
3 : 1	2·5
4 : 1	3·2

The speed ratio of col (1) in this table shall be the ratio of actual speed under consideration to the minimum rated speed for continuous running.

For speed ratios other than these given in this table, the appropriate multiplying factors can be ascertained by interpolation.

4.2.2 *Braking Test* — The machine is run at rated conditions of speed, voltage and current and the efficiency is taken as the ratio of output to input measured in the same units.

NOTE — No winding resistance temperature correction shall be made to the machine under test.

4.2.3 *Calibrated Machine Test* — The machine is run at rated conditions of speed, voltage and current and the efficiency is taken as the ratio of output to input measured in the same units (*see* **7.2**).

NOTE — No winding resistance temperature correction shall be made to the machine under test.

4.2.4 *Mechanical Back-to-Back Test* — The identical machines are run at essentially the same rated conditions, the losses are assumed to be equally distributed, and the efficiency is calculated from half the total losses and the electrical input.

4.2.5 *Electrical Back-to-Back Test* — The identical machines are run at essentially the same rated conditions, the losses supplied from the electrical system are assumed to be equally distributed and the efficiency is calculated as **4.2.4** above.

5. DETERMINATION OF QUANTITIES FOR POLYPHASE INDUCTION MACHINES

5.1 Losses — The total loss consist of the following component losses.

5.1.1 *Losses Independent of Current*

a) *Core loss* — Core loss at no-load speed, with rated terminal voltage and rated frequency.

b) *Bearing friction loss* — Only losses in bearings supplied with the machine shall be included. Losses in common bearings shall be stated separately whether or not they are supplied with the machine.

c) *Total windage loss* — The total windage loss in the machine and auxiliary machines, if any, including the power absorbed in fans forming an integral part of the machine. The losses in external fans provided exclusively for the machine in question shall be included only by agreement. When the machine is ventilated from a common independent air supply, the windage losses in ventilating ducts external to the machine housing, and those of the external fans supplying air through such external ducts, shall not be included.

d) *The brush friction loss* — included when brushes are not lifted.

5.1.2 *Direct-Load Losses*

a) The I^2R loss in the primary windings.

b) The I^2R loss in the secondary windings on load.

c) The summation of the I^2R loss in brushes and connectors, and brush-contact loss.

5.1.3 *Stray-Load Losses*

a) The stray-load loss in the magnetic circuit and any other metal parts other than the conductors.

b) The stray-load loss in conductors.

NOTE — In the case of auxiliary machines, such as phase advancers driven mechanically from the main shaft the losses in such auxiliary machines should be included in the same way as the exciter losses are included for synchronous machines. Losses in separately driven phase advancers or regulating sets should not be included.

5.2 Determination of Efficiency

5.2.1 *Summation of Losses* — The efficiency can be calculated from the total losses which are assumed to be the summation of the losses obtained in the following manner.

5.2.1.1 *Losses independent of current* — These are determined as follows:

a) *No-load test at rated voltage* — The sum of the losses independent of currrent is determined by running the machine as a motor on no-load. The machine is fed at its rated voltage and frequency. The power absorbed, decreased by the I^2R losses in the stator, gives the total of the independent losses. (The I^2R losses in the rotor may be neglected.)

b) *Calibrated machine test* — The losses **5.1.1** (b), **5.1.1** (c) and **5.1.1** (d) may be determined separately by driving the machine, disconnected from the network, at its rated speed by means of a calibrated motor (*see* **5.2.3**). With the brushes, if any, in place, the power absorbed at the shaft of the machine, which may be deduced from the electrical power absorbed by the calibrated motor, gives the sum of the losses, **5.1.1** (b) + **5.1.1** (c) + **5.1.1** (d). With the brushes, if any, lifted, the sum of the losses **5.1.1** (b) + **5.1.1** (c) is obtained in the same manner. Losses in **5.1.1** (a) may be obtained from the preceding by subtraction.

c) *No-load test at variable voltage* — The losses may also be separated by running the machine as a motor at rated frequency, but at different voltages. The power absorbed, less the I^2R losses in the primary, is ploted against the square of the voltage. This at low saturation, will give a straight line which can be extrapolated to zero voltage.

It should be borne in mind that, at very low voltage, losses plotted on the diagram may be high because of the increased secondary losses with increased slip. When plotting the straight line, this part of the diagram should not be taken into account.

In the above manner the sum **5.1.1** (b) + **5.1.1** (c) + **5.1.1** (d) is obtained and hence **5.1.1** (a). If the motor is started with short-circuited secondary and the brushes are lifted (which is possible if the supply generator is started with the motor), **5.1.1** (b) + **5.1.1** (c) are obtained at zero voltage.

5.2.1.2 *Direct-load losses*

a) *Load test* — The losses in **5.1.2** (a) are calculated from the resistance of the primary windings measured, using direct current, and corrected to the reference temperature, and from the current corresponding to the load at which the losses are being calculated.

To determine the losses **5.1.2** (b) when an on-load test is made, the secondary losses are taken to be equal to the product of the slip and the total power transmitted to the secondary winding,

that is, the power absorbed decreased by the core losses **5.1.1** (a) and the I^2R losses in the primary winding [*see* **5.1.2** (a)]. This method gives directly the sum of the losses **5.1.2** (b) + **5.1.2** (c) for slipring machines, and the losses **5.1.2** (b) for squirrel cage machines. For this latter type of machine, this is the only applicable method as it is not possible to measure the resistance of the secondary winding directly. When use is made of this method, the slip may be measured by a stroboscopic method or by counting the beats of a permanent-magnet millivoltmeter, connected between two rings (for motors with wound secondary windings) or the terminals of an auxiliary coil (motors with short-circuited secondary winding) or between the ends of the shaft.

b) *Calculated values* — For slipring motors, the losses in **5.1.2** (b) may be calculated from the resistance measured by dc and corrected to the reference temperature, and from the secondary current calculated from a circle diagram, account being taken of the true transformation ratio of the machine.

c) *Additional losses* — Unless it is possible to make an on-load test, the losses in **5.1.2** (c) in the brushes cannot be measured directly and these losses shall be taken as the product of the current flowing in the brushes and a fixed voltage drop. The voltage drop in all brushes of the same phase shall be taken as 1·0 volt for carbon or graphite brushes, and 0·3 volt for metal-carbon brushes.

5.2.1.3 *Stray-load losses* — Unless otherwise specified, it is assumed that the losses **5.1.3** (a) and **5.1.3** (b) vary as the square of the primary current and that their total value at full load is equal to 0·5 percent of the rated output.

5.2.2 *Braking Test* — When the machine is run at rated conditions of speed, voltage and current, the efficiency is then taken as the ratio of output to input measured in the same units.

NOTE — No winding resistance temperature correction shall be made to the machine under test.

5.2.3 *Calibrated Machine Test* — When the machine is run at rated conditions of speed, voltage and current, the efficiency is then taken as the ratio of output to input measured in the same units (*see* **7.2**).

NOTE — No winding resistance temperature correction shall be made to the machine under test.

5.2.4 *Mechanical Back-to-Back Test* — When identical machines are run at essentially the same rated conditions, the losses are assumed to be equally distributed, and the efficiency is calculated from half the total losses and the electrical input. The driven machine shall operate as an induction generator if a source of magnetizing kVAR is provided, and a suitable load is connected to its terminals.

5.2.5 *Electrical Back-to-Back Test* — When identical machines are run at essentially the same rated conditions, the losses supplied from the electrical system are assumed to be equally distributed and the efficiency is calculated from half the total losses and the electrical input to one machine.

6. DETERMINATION OF QUANTITIES FOR SYNCHRONOUS MACHINES

6.1 Losses — The total loss consist of the following component losses.

6.1.1 *Exciting-Circuit Losses*

a) *Field I^2R loss* — The I^2R loss in the field winding.

b) *Main rheostat loss* — The loss in the rheostat in the main exciting circuit.

c) *Electrical loss in brushes* — The summation of I^2R losses in brushes and connectors, and brush-contact loss.

d) *Exciter loss* — All the losses in an exciter mechanically driven from the main shaft which forms part of the complete unit, and is used solely for exciting the machine, together with losses in the rheostat in the field circuit of such an exciter, with the exception of bearing loss which is included in **6.1.2** (b), windage loss which is included in **6.1.2**(c) and brush friction which is included in **6.1.2** (d).

Losses in a gear or rope, or similar drive, between main shaft and exciter should be included.

All the losses in any apparatus for self-excitation and regulation receiving its input from the ac lines connected to the terminals of the synchronous machine.

In case of separate excitation by other means, such as a battery, rectifier or motor-generator set, no allowance for losses of the excitation source is to be made.

6.1.2 *Losses Independent of Current*

a) *Core loss* — Core loss at no-load and rated speed and rated terminal voltage.

b) *Bearing friction loss* — Only losses in bearings supplied with the machine shall be included. Losses in common bearings shall be stated separately whether or not they are supplied with the machine.

For vertical shaft machines, losses in a thrust-bearing and if combined with a guide-bearing, the total losses in the bearings, shall be stated separately. The thrust-load, the temperatures in the bearings and grade of oil at which the loss values are valid, shall also be given.

By agreement, the bearing temperature may be measured in two pads of the thrust-bearing and two pads (points) of the guide-bearing, and the stated value referred to the highest of the measured temperatures. The load on the thrust-bearing should be the same as when measuring the losses. For information, the bearing losses when the bearing is loaded with total weight of rotating parts plus full hydraulic thrust may be given.

c) *Total windage loss* — The total windage loss in the machine and exciter, if any, including the power absorbed in fans forming an integral part of the machine. The losses in external fans provided exclusively for the machine in question shall be included only by agreement. When the machine is ventilated from a common independent air supply, the windage losses in ventilating ducts external to the machine housing, and those of the external fans supplying air through such external ducts, shall not be included.

d) *Brush friction loss* — The brush friction, including that of the exciter if mechanically driven.

6.1.3 *Direct-Load Losses* — The I^2R loss in the primary windings determined from the current and the resistance of the windings.

6.1.4 *Stray-Load Losses*

a) Stray-load loss in the magnetic circuit and any other metal parts other than the conductors.

b) Stray-load loss in conductors.

6.2 Determination of Efficiency

6.2.1 *Summation of Losses* — The efficiency can be calculated from the total losses which are assumed to be the summation of the losses obtained in the following manner.

6.2.1.1 *Exciting-circuit losses*

a) *Field I^2R losses* — These losses are calculated from the formula I^2R, taking for R the resistance of the field winding corrected to the reference temperature and for I the value of the exciting current for the particular rating of the machine, measured directly during the on-load test or calculated when this test is not possible. Where such a calculation is made, the method is for agreement between manufacturer and purchaser.

b) *Main rheostat losses* — These losses are calculated from the formula I^2R, where R is the resistance of the part of the rheostat in circuit for the rating considered, and I is the value of the exciting current for the rating considered defined as in **6.2.1.1**(a). They are also equal to the product IU of the excitation current at the particular rating and the voltage U at the terminals of the rheostat.

c) *Brush electrical losses* — The sum of these losses shall be taken as the product of the excitation current at the rating considered and a fixed voltage drop. The voltage drop allowed for all brushes of each polarity shall be 1·0 volt for carbon or graphite brushes and 0·3 volt for metal-carbon brushes, that is, a total drop of 2·0 volts for carbon or graphite brushes, and 0·6 volt for metal-carbon brushes.

The sum of the losses **6.2.1.1** (a) + **6.2.1.1** (b) + **6.2.1.1** (c) is also equal to the product IU_e of the exciting current I and the total excitation voltage U_e.

d) *Exciter losses*

These losses include the difference between the power absorbed at the shaft of the exciter and the useful power which it furnishes at terminals of the exciter, and the excitation losses of the exciter if this machine itself is excited by a separate source. The useful power at the terminals of the exciter is equal to the sum of the losses **6.2.1.1** (a) + **6.2.1.1** (b) + **6.2.1.1** (c) of the main machine.

If the exciter can be uncoupled from the main machine and tested separately, the power which it absorbs may be measured by the calibrated machine method (*see* **6.2.3**).

If the exciter cannot be uncoupled from the main machine, the power which it absorbs may be measured either by the calibrated machine method (*see* **6.2.3**) or by the retardation method (*see* **7.4**) applied to the complete group. In these two methods, the power absorbed by the exciter is obtained as the difference between the total losses of the group measured under identical conditions, first with the exciter on load, secondly with the exciter unexcited, the excitation of the exciter being furnished by an independent source.

If none of these methods is applicable, the power absorbed by the exciter is obtained by adding to the power measured at its terminals the several separate losses determined as described under **4.1**. Nevertheless, mechanical losses due to friction and windage which are measured at the same time as those of the main machine are not taken into account.

The method of determining the losses in apparatus for self excitation and regulation, receiving their input from the ac lines connected to the terminals of the machine shall be a matter of agreement between manufacturer and purchaser.

NOTE — The above methods of obtaining exciter losses apply only to the case where the exciter is mechanically driven from the main shaft and is used solely for exciting the synchronous machine.

6.2.1.2 *Losses independent of current*

a) *Unity power factor test at rated voltage and frequency* — The sum **6.1.2** (a) + **6.1.2** (b) + **6.1.2** (c) + **6.1.2** (d) of the losses independent of current is generally determined by the method of running the machine as a motor on no-load. The synchronous machine is fed at its rated voltage and rated frequency, so as to work as a motor on no-load. The excitation is adjusted so that the machine absorbs the minimum alternating current. The electrical power absorbed, decreased by the I^2R loss in the stator windings, and, if appropriate, by the power absorbed by the exciter gives the sum of the losses independent of current.

b) *Open-circuit test* — The sum of the losses **6.1.2**(a) + **6.1.2**(b) + **6.1.2** (c) + **6.1.2** (d), the losses **6.2.1** (a) and the sum of the losses **6.1.2** (b) + **6.1.2** (c) + **6.1.2** (d) may also be determined by driving the machine at its rated speed by means of calibrated machine (*see* **7.2**). The machine is excited by an independent source so as to work as a generator on no-load at a voltage equal to its rated voltage. The power which it absorbs at its shaft, and which may be calculated from the power absorbed from the calibrated motor, gives the sum of the losses **6.1.2** (a) + **6.1.2** (b) + **6.1.2** (c) + **6.1.2** (d). By removing the excitation, the sum of the losses **6.1.2** (b) + **6.1.2** (c) + **6.1.2** (d) is obtained in the same manner. The core losses **6.1.2** (a) are obtained by subtraction. Given the small number of brushes used of synchronous machines, it is generally not possible to separate the losses **6.1.2** (d) from the sum of the losses **6.1.2** (b) + **6.1.2** (c) + **6.1.2** (d), by means of a test with the brushes lifted.

c) *Retardation test* — The sum of the losses **6.1.2** (a) + **6.1.2** (b) + **6.1.2** (c) + **6.1.2** (d), the losses **6.1.2** (a) and the sum of the losses **6.1.2** (b) + **6.1.2** (c) + **6.1.2** (d) may be determined by using the retardation method (*see* **7.4**).

d) *Unity power factor test at variable frequency* — The losses may be separated by running the machine as a motor at rated frequency, but at different voltages as described under **5**.

e) *Variable hydrogen density test* — The total windage losses **6.1.2** (c) may be separated from bearing friction losses **6.1.2** (b) and brush friction losses **6.1.2** (d) by tests at different densities of cooling gas for hydrogen cooled machines.

NOTE — Tests at different speeds are under consideration.

f) *Calorimetric test* — The losses **6.1.2** (b) may be separately determined when possible by using the calorimetric method.

NOTE — Test on losses in thrust-bearings, possibly combined with guide-bearings, in vertical shaft machines, should only be carried out by agreement.

6.2.1.3 *Direct-load losses* — I^2R loss in armature windings is normally measured during the short-circuit test described in **6.2.1.4**.

When it is to be given separately, the loss is calculated from the current and the resistance of the windings corrected to the reference temperature.

6.2.1.4 *Stray-load losses* — Unless otherwise specified, the sum of the losses **6.1.4** (a) + **6.1.4** (b) is measured by means of the short-circuit test. The machine to be tested, with its armature winding short-circuited, is driven at its rated speed and so excited that the current in the short-circuited armature is equal to the rated current. The power absorbed at the shaft, decreased by the mechanical losses **6.1.2** (b) to **6.1.2** (d), and the power absorbed by the exciter, if appropriate, presents the sum of the I^2R losses **6.1.3** and the stray-load losses **6.1.4** (a) and **6.1.4** (b). The losses **6.1.3**, **6.1.4** (a) and **6.1.4** (b) vary in different senses as a function of the temperature. The sum of the losses **6.1.3** + **6.1.4** (a) + **6.1.4** (b) is assumed to be independent of the temperature, and no correction is made to the reference temperature.

NOTE — It is recognized that the sum of the losses **6.1.4** (a) + **6.1.4** (b), thus determined, is generally a little higher than the losses which actually exist at full load.

The power absorbed at the shaft of the machine during the short-circuit test may be measured by the calibrated machine method or by the retardation method (*see* **7.4**).

6.2.2 *Braking Test* — When the machine is run at rated conditions of speed, voltage and current, the efficiency is taken as the ratio of output to input measured in the same units.

NOTE — No winding resistance temperature correction shall be made to the machine under test.

6.2.3 *Calibrated Machine Test* — When the machine is run at rated conditions of speed, voltage and current, the efficiency is taken as the ratio of output to input measured in the same units. (*see* **7.2**).

NOTE — No winding resistance temperature correction shall be made to the machine under test.

6.2.4 *Mechanical Back-to-Back Test* — When the identical machines are run at essentially the same rated conditions, the losses are assumed to be equally distributed, and the efficiency is calculated from half the total losses and the electrical input.

6.2.5 *Electrical Back-to-Back Test* — When the identical machines are run at essentially the same rated conditions, the losses supplied from the electrical system are assumed to be equally distributed and the efficiency is calculated from half the total losses and the electrical input.

6.2.6 *Zero Power Factor Test* — The machine operates as a motor at no-load and at rated speed with a power-factor in the neighbourhood of zero whilst the excitation current is adjusted so as to have the rated primary current.

The supply voltage is such that the magnetic losses have the same value as in no-load operation under rated voltage. In principle, the reactive power supplied should be positive (that is, over-excited), but when this is impossible because the exciter voltage is not sufficient, the test can be made with absorption of the reactive power (that is, under-excited).

The total losses are equivalent to the absorbed power during the test corrected for the exciting-circuit losses.

7. METHODS OF TEST

7.1 Tests can be grouped in one of the following three categories:

a) Input-output measurement on a single machine. This usually involves the measurement of mechanical power into, or out of a machine.

b) Input and output measurement of two machines connected back-to-back, for example, two identical machines or a test machine coupled to a calibrated machine.

c) Measurement of the actual loss in a machine under a particular condition. This is usually not the total loss, but comprises component losses. The method may, however, be used to calculate the total loss.

The choice of tests to be made depends on the information required, the accuracy required, and the type and size of machine involved. Where alternative methods are available for a particular type of machine, the preferred method shall be in accordance with **8**.

When the efficiency or total loss is derived from the measured input and output power, any inaccuracy in these measurements appears as a direct error in the efficiency (for example, with an accuracy of power measurement not better than 1 percent, the efficiency can be 2 percent in error or the total losses can be in error by 2 percent of the total input power). On small machines or machines with relatively low efficiencies (say, below 90 percent), this method may be quite acceptable and forms a convenient form of test for such machines. On these and on other machines, efficiency can be obtained with high accuracy by the calculation of losses from direct measurements.

7.2 Calibrated Machine Test — The machine of which the losses are to be measured is separated from the network, uncoupled from its driving motor, if necessary, and driven at its rated speed by a calibrated motor, that is, by an electric motor of which the losses have been previously determined with great accuracy, such that it is possible to determine the mechanical power which it furnishes at its shaft, knowing the electric power which it absorbs and its speed of rotation. The mechanical power transmitted by the calibrated motor to the shaft of the machine under test is a measure of the losses of this latter machine for the working conditions under which the test is made. In this method, the machine tested may be on no-load, excited or unexcited, with or without brushes or short-circuited, which enables categories of losses to be separated.

7.2.1 As an alternative, the calibrated motor may be replaced by a dynamometer or by any other motor driving the machine under test through an appropriate torsionmeter, which enables the torque transmitted to the machine under test to be known, and hence the mechanical power absorbed by this latter machine.

When use is made of this alternative, the speed of rotation which comes directly into the calculation of the torque shall be measured with extreme care.

7.3 Zero Power Factor Test — Under consideration.

7.4 Retardation Method — This method is applicable to large machines with considerable inertia. It consists of measuring the retardation time when the machine is slowing down under different conditions between two predetermined speeds, say, from 110 percent to 90 percent or from 105 percent to 95 percent of the rated speed. This time varies inversely with the average losses during the same time.

The method enables the measurement of the mechanical loss (bearing friction, total windage loss and brush friction) with any machine, core loss at different excitation and load loss at short-circuit under different excitation only with dc and synchronous machines.

During the test, the machine is run as a motor at no-load fed from a separate generator. The machines are accelerated to a speed sufficiently above the speed from which the retardation time is measured. The test machine is then disconnected from its feeding machine and the excitation and connection conditions, which are to be studied, are established. This should be done with sufficient rapidity for the electrical test conditions to have been reached at the moment when the speed of the machine, which is decreasing constantly during this interval, passes through the upper limit, from which the retardation time is measured.

The time between the two limits should be measured with an accuracy of preferably 1 to 2 percent. The interval between the two limits chosen depends on the accuracy of measurement. A permanent-magnet generator or an exciter may be used as a tachometer.

The test should be carried out for several excitations, both with open-circuit and short-circuit connections. In the open-circuit retardation tests, the excitation current and the stator voltage are measured as the machine passes through the rated speed. In the short-circuit retardation tests, the excitation current and the stator current are measured at the same instant.

Before the measurements, the machine is run for a sufficient time for the temperature of the bearings to be stabilized. If the bearing losses are guaranteed at a certain temperature of the bearing, the amount of cooling water to the bearing cooling system should be adjusted so that the agreed temperature is attained.

To obtain the absolute value of the losses, which are present in the machine during the corresponding open-circuit retardation test at the moment of passing through the rated speed, measurements are made with the machine running as a motor at no-load, normal speed and unity power-factor, and at the same voltage as in one of the retardation measurements preferably at normal voltage. The input, that is the losses, is to be measured with great accuracy.

The measurement is repeated several times and the average value calculated. Instead of measuring several times at the same voltage, several points can be measured at different voltages in the range of 95 to 105 percent to obtain a curve of losses *versus* voltage around the rated voltage. Retardation measurements should have been made in the same voltage range. The relation between losses P and retardation time is now established.

The losses at any condition (for example, at no-load, at short-circuit, etc) are calculated as the input value P measured in the above test multiplied by the ratio between the retardation time in the above test and the retardation time in the actual test.

The mechanical loss is obtained from a retardation test without excitation, the core loss from the open-circuit tests with mechanical loss subtracted and loss in short-circuit from a retardation test in short-circuit with mechanical loss subtracted.

When the intertia of the machine is not known with sufficient precision, it may be determined by a retardation test with known losses, measured by another method.

The moment of inertia is calculated from the results of the retardation test by the equation:

$$J = \frac{45\,600\ t P}{\delta n^2}$$

where

J = moment of inertia in kgm^2,

t = time in seconds for retardation from the speed $n(1+\delta)$ to the speed $n(1-\delta)$,

P = in losses kW, and

n = rated speed in rev/min.

In retardation test, the excitation for the machine under test should preferably be from a separate source. A directly coupled exciter may, however, be used. if the interval in speed at retardation is small, for example, 105-95 percent. An appropriate correction for the loss in the excitation circuit shall then be made taking into account also that the excitation current at the retardation test, and the no-load test may be a little different, although the voltage is the same. Separate excitation of the exciter is, however, necessary.

Instead of using the no-load method for obtaining the absolute value of the losses, the calibrated motor method may be used.

7.4.1 The on-load retardation test is conducted with the machine operating as a motor and supplying the load. The speed of rotation of the unit before disconnecting from the network should approximately be equal to the rated speed. The power input before disconnecting should be not less than 0·6 of the rated power; and for synchronous machines the power factor should be close to unity. The excitation of dc and synchronous machines during the test is unchanged.

After disconnecting the supply source, the change of speed of the unit during the first few seconds is determined.

The speed-time curve is plotted and a tangent to the initial point of the curve is drawn. This tangent is used to determine the change in speed for the time interval.

7.5 Calorimetric Test — Under consideration.

7.6 Electrical Back-to-Back Test

7.6.1 This method is applicable when two identical machines are available, especially in the case of direct current. The machines are coupled mechanically and electrically so as to operate at rated speed, one as a motor and the other as a generator. The actual temperature at which the measurements are carried out should be as close as possible to the working temperature and no further correction should be made. The losses of the assembled machines are supplied either by a network to which they are connected, or by a calibrated driving motor, or by a booster, or by a combination of these various means.

7.6.2 The average value of the armature currents is adjusted at the rated armature current value, the average of the voltage of the two armatures is above or below the rated voltage by an amount equal to the voltage drop, according to whether the machines are meant to be used respectively as generators or as motors.

7.6.3 Where two induction machines are electrically connected, they should be mechanically coupled with a speed adjusting device such as a gear box to ensure the circulation of power. The magnitude of power circulated depends upon the difference in speed. The electrical system supplying the losses to the two machines shall be required to provide magnetizing kVAR to both machines.

7.6.4 When two synchronous machines are electrically connected, they should be mechanically coupled with a correct angular phase relationship. The magnitude of the power circulated depends upon the difference in phase angle between them.

7.7 Mixed Frequency Test — Under consideration.

8. SCHEDULE OF PREFERRED TESTS

8.0 The schedule of preferred tests for various machines shall be as follows.

8.1 For dc Machines — The preferred test shall be in accordance with **7.6**, with the efficiency calculated in accordance with **4.2.1**.

8.2 For Induction Machines — The preferred test shall be in accordance with **5.2.1.1** (a) and **5.2.1.2** (a), losses independent of current being determined in accordance with **5.2.1.1**.

8.3 For Synchronous Machines — The preferred test shall be in accordance with **6.2.1.2** (b) and **6.2.1.4**, losses independent of current bieng determined in accordance with **6.2.1.2**.

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